Colliding Pulse Mode-Locked VECSEL

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Abstract: We report for the first time a colliding-pulse modelocked VECSEL, with the gain and SESAM inside a ring cavity. We obtained output power of 2.2W, repetition rate of 1GHz and pulse duration of 1.16ps.

1. Introduction

Vertical-External-Cavity Surface-Emitting Lasers (VECSELs) are considered prime candidates for use as single-mode, widely tunable lasers in a variety of applications, ranging from laser cooling and atomic spectroscopy, to telecommunications. Pumping of these devices is possible both electrically and optically. Due to their high photoluminescence efficiency, optically pumped VECSELs are primarily used in applications where high power single mode emission is required, whereas electrically pumped devices are more commonly used in applications involving near infrared frequency doubling[1]. When a Semiconductor Saturable Absorber Mirror (SESAM) is placed inside the cavity, mode locking operation can occur, generating a high power pulsed output with gigahertz pulse repetition rate and sub-picosecond pulse durations[2, 3]. Lasers with these properties can be commercially used as sources in many fields including frequency metrology, high-speed optical communication systems and high-resolution optical sampling.

Modelocked VECSELs are usually set up in a V-cavity configuration with an output coupler and SESAM both pointed toward the VECSEL gain[2, 3]. In this configuration, the VECSEL usually operates in a fundamental modelocking regime, where only one pulse travels in the cavity and will thus hit the SESAM and output coupler once per round trip and will hit the gain chip twice per round trip.

In this work, we investigated a novel cavity design, where the VECSEL chip and SESAM are placed in a ring cavity. With this geometry, there is no preferred direction of travel, and the cavity can support counter propagating pulses. If the cavity is designed properly, it is possible to synchronize two counter-propagating pulses in the SESAM such that the absorber is more efficiently saturated, thus minimizing the energy lost per round trip.

2. Colliding pulse Modelocking in a VECSEL

In a ring laser cavity without direction selective elements, two pulses can propagate, clockwise and counterclockwise. If the absorption of the saturable absorber is strong enough, it can force the two pulses to synchronize in the cavity such that they collide in the absorber. The superposition of the two pulses can cause a transient stationary wave, creating a transient phase and amplitude modulation further increasing the field intensity on the SESAM. The saturation of the SESAM is thus more effective and the losses minimized for each pulse.

For the amplification of the two pulses to be symmetrical, the VECSEL and the SESAM have to be placed in the cavity according to the geometry shown in Figure 1. The gain medium is placed a quarter of the total cavity length from the saturable absorber, thus the total pumping duration is the same for both pulses. However, this geometrical rule is not very stringent as long as the gain fully recovers between two consecutive pulses. It has been shown[4] that after the passage of a pulse, the population inversion in a VECSEL can recover to more than 80% of its initial value within 5 ps.

Similar to conventional modelocked VECSEL cavities, the duration of the produced pulses depends on the combination of three mechanisms. First, the gain saturation velocity, which is responsible for the shortening of the trailing edge of the pulse. Secondly, the absorption process clips the front edge of the pulse. Finally, the time-shortening by the gain and absorption saturation is balanced by the group velocity dispersion. In the steady state, the laser will run within the available gain bandwidth, with a pulse duration which is the balance of these various effects.

The main advantage of the ring cavity configuration is the reduction of the effective saturation fluence of the absorber. This results in a lower lasing threshold and allows higher output power since the mode size on the SESAM doesn't have to be much smaller than the mode size on the VECSEL. This also enables the use of SESAM with higher modulation depth, thus enhancing modelocking stability.

3. Experimental Setup

A VECSEL system with a ring cavity geometry was constructed. This laser consists of an optically pumped semiconductor laser (OPSL) gain chip with an antireflective coating, a SESAM, a highly reflective concave mirror with a radius of curvature of 30 mm, and a partially transparent flat output coupler with a reflectivity of 99%. The OPSL and SESAM each contain a semiconductor Bragg reflector and a QW-based gain region and absorption region respectively region. Both were mounted on a copper plate heat sink with their temperatures stabilized using independently controlled water cooled Peltier elements. The pump laser used to excite the OPSL has a central frequency of 808 nm.

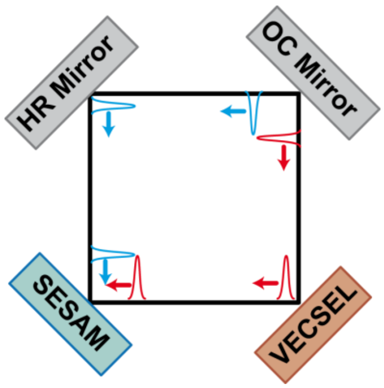

Figure 1. Circulation of the two pulses in a ring cavity system. The two counter-propagating pulses cross in the SESAM.

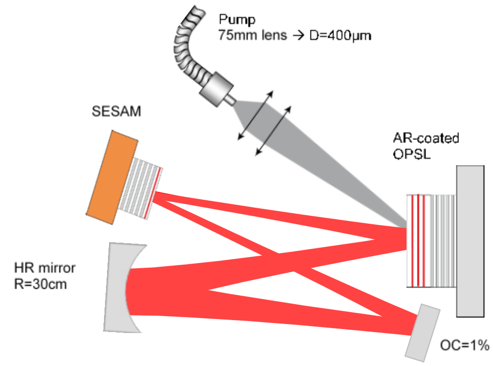

Figure 2. Schematic layout of the colliding pulse modelocked VECSEL.

The SESAM and HR concave mirror are each positioned 70mm from the OPSL gain chip, exactly one quarter of the total cavity length. The output coupler is positioned such that the lengths of the two separate paths from the concave mirror onto the SESAM total 140mm. The mode size on the gain chip was about 20% bigger than the pump size to ensure single transverse mode operation. The mode size on the SESAM was only 10% smaller than the mode size on the gain medium. We should note that in a standard V-cavity modelocked VECSEL, a Gain/SESAM mode ratio of 2 or more is generally necessary to obtain a stable modelocking regime. This restriction is lifted here since the saturation of the SESAM is more effective when the two counter propagative pulses synchronize and saturate the absorber together.

The GaAs-based OPSL gain structure was grown by Metal-Organic Vapor Phase Epitaxy (MOVPE) for an emission around 1µm. The structure is composed of a half wavelength InGaP confinement layer, a Resonant Periodic Gain structure (RPG) and a high-reflectivity AlAs/GaAs Bragg mirror. The active region consists of 10 InGaAs QWs, placed at the anti-nodes of the standing optical field, and are surrounded by pump-absorbing GaAs(P) barriers. The Bragg mirror is composed of 22.5 AlAs and GaAs quarter wavelength layer pairs. After processing, an antireflection coating was applied. We should note that this chip was designed and optimized for high power CW operation[5], but not optimized for ultrashort pulse generation, for which a broader gain bandwidth and a minimization of the Group Delay Dispersion (GDD) are necessary[6]. It was however adequate to demonstrate the proof of principle of this novel cavity design.

The SESAM structure consists of a highly reflective AlAs/GaAs Bragg mirror of 28 pairs, followed by an InGaAs QW placed close to the surface. The proximity with the surface provides a faster recombination time as the generated carriers can tunnel through the thin barrier to recombine on the various defects states at the surface. The amount of absorption from the SESAM is about 1% and can be slightly adjusted by changing the temperature, as the absorption edge of the QWs shift with temperature at a rate of 0.3nm/K.

4. Modelocking Results

After a careful optimization of the VECSEL and SESAM temperature, we achieved a stable fundamental modelocking regime with an output maximum output power of 1.1W for each of the two counter propagating beams giving a total output power of 2.2W from a pump power of 14.8W.

The pulse duration was measured using a second harmonic intensity autocorrelator. Depending on the pump power level and temperatures of the VECSEL and SESAM, the pulses ranged from 1ps to 3ps. At the maximum output power of 2.2W, the pulses presented a pulse duration of 1.16ps. The autocorrelation trace is presented on Figure 3. The corresponding optical spectrum was measured to have a maximum at 1007nm and a FWHM of 3.1nm. The resulting time bandwidth product of 1 suggests that shorter pulses can be obtained with adequate dispersion compensation.

In order to verify that the system is running on a fundamental modelocking regime, the RF spectrum shown on Figure 4, was measured using a fast photodetector. The system exhibits a pulse repetition rate of 1.075GHz with an extremely narrow linewidth, characteristic of a stable modelocking regime. The signal is about 60dB above the noise floor. A full span measurement, up to 6GHz also confirmed the presence of all the harmonics with similar amplitude levels.

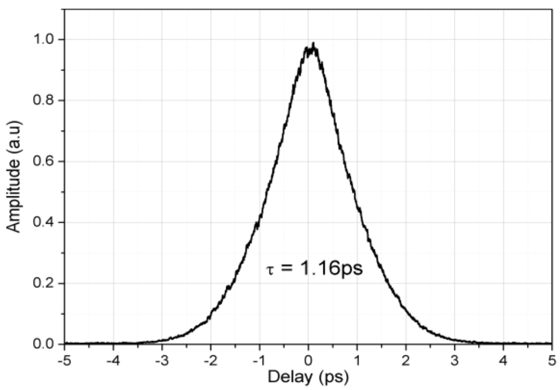

Figure 3. Autocorrelation trace of the output pulses. The pulses duration is about 1.16ps assuming a sech2 profile.

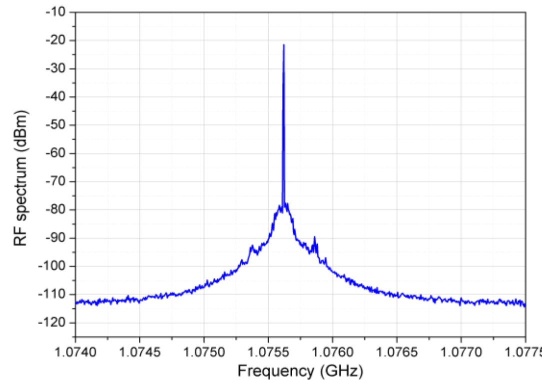

Figure 4. RF spectrum of the output pulses. The repetition rate of 1.0755 GHz is in agreement with the cavity length.

5. Summary

We presented an important proof-of-principle experiment that demonstrates that colliding pulses modelocking techniques can be implemented in a VECSEL cavity. This novel cavity geometry can be used to increase stability, reduce intra cavity losses and lower modelocking threshold. A total output power of 2.2W was obtained at a repetition rate of about 1GHz. We measured pulse duration ranging from 1ps to 3ps, with a pulse of 1.16ps at maximum power. The optical spectrum was centered on 1007nm with a FWHM of 3.1nm. Given the time bandwidth product of 1, it should be possible to reduce the pulse duration through external dispersion compensation techniques. More importantly, we believe that an optimization of the GDD and gain bandwidth of the gain chip would allow generation of pulses in the sub 200fs regime. This geometry can also be used with multiple gain chips within the one cavity. This would lead to a higher and broader gain, leading to higher total output power and shorter pulses.

6. Acknowledgments

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7. References

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